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Detecting and Measuring Pelagic Fish Schools Using Remote Sensing Techniques

by

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Abstract

Aerial survey techniques are known to be useful in monitoring and assessing pelagic fish stocks which school near the surface. In the Northwest Atlantic capelin (*Mallotus villosus*) schools have been surveyed using aerial colour photography since 1982. Following extensive comparative tests conducted in 1989 we have replaced the photographic method with digital imagery collected by the Compact Airborne Spectrographic Imager (CASI) to conduct recent surveys of capelin schools in 1990-93. The CASI is a recently developed instrument which can be operated in spatial and spectral modes. Features allow the operator to view the imagery as it is being collected in the aircraft and to program the number, position, and widths of spectral bands in flight. The digital data are recorded on 8 mm video cassettes which can be examined in near real time on a PC-based image analysis system following each flight. Follow-up analysis including image classification and enhancement supports the enumeration and areal estimate of fish schools. Some degree of interpretation by field observers is still required but is substantially less than required with aerial photography. Weather continues to limit the frequency and duration of flights however the CASI can detect and record fish schools in overcast conditions when aerial photography would not have been feasible. The results of aerial surveys using CASI have been applied to support stock assessments of capelin. The CASI has also been successfully used to detect herring schools.

Introduction

Spawning biomass is estimated annually from hydroacoustic surveys conducted on pre-spawning fish. Indices of abundance based on commercial catch rates and aerial photographic surveys conducted during the spawning season are used to verify annual mature biomass trends projected from acoustic estimates (Carscadden et al. 1993). Aerial photographic surveys have been conducted since 1982 to monitor capelin (*Mallotus villosus*) schools which occur in coastal waters (<25 m depth) in June and July prior to spawning on gravel beaches along the Newfoundland coast. Survey transects in Trinity Bay and Conception Bay are flown daily weather permitting (Fig. 1). Experienced observers identify fish schools which are then photographed at known altitudes. Once prints are developed the number and area of fish schools are measured. The total surface area of all schools along a transect has been employed as an index of relative abundance in annual assessments of capelin stocks in NAFO Div. 3L since 1985 (eg. Nakashima 1988).

Aerial surveys provide more frequent and greater coverage of the coastline than research vessel surveys, however aerial photography imposes several limitations on data collection and data quality. Aside from the obvious down time due to weather restrictions, colour aerial photography is best confined to sunny days when the sun angle is between 25 and 45 degrees. At a latitude of 47°N the effective photographic time occurs at 0730-1100 and 1600-1930. Fish schools can not be readily distinguished from the background when photographs are too dark or have too much sun glint. The quality of the photographs are unknown until negatives are developed typically several weeks after the capelin schools have spawned and migrated out of the nearshore areas. Thus lack of data due to poor photography or inadequate coverage can not be recovered. Capelin schools on photographic prints are counted and the surface area of each school measured with a planimeter. This process is highly subjective, time-consuming and laborious, often requiring several months before all schools are identified, counted and their areas measured.

To overcome some of the restrictions associated with the aerial photographic technique and to hasten the analysis of survey data, test flights were conducted which utilized a Compact Airborne Spectrographic Imager (CASI) to digitally image capelin schools during the 1989 spawning season. Preliminary tests conducted on capelin in July 1988 (Nakashima et al. 1989) and on Pacific herring (Clupea pallasi) in March 1989 (Borstad et al. 1992) demonstrated that the CASI could be deployed to detect pelagic fish schools. The results reported in this study describe the detection process and its potential application for improving the quality and use of airborne spectrographic imagery to aid in the assessment of capelin stocks in the northwest Atlantic Ocean.

Material and Methods

Aerial survey missions were flown between June 18 and July 4, 1989 to collect CASI and photographic data on capelin schools. As an example of the detection process one image collected on June 18 in Conception Bay has been chosen to illustrate the process. The imagery was collected at 457 m altitude above sea level using a Piper Chieftain. Coincident photographic data to compare with CASI imagery were collected using a Ziess PMK photo-mapping camera with a 153 mm lens to identify capelin and other features. All aerial photographs were developed from colour negative film (Kodak Aerocolour Negative 2445 Film) which allows some water penetration (Nakashima 1988).

The CASI (Fig. 2) is an imaging spectrometer which uses a two dimensional (612 X 288) charge couple device (CCD) and a diffraction grating to collect image and spectral data (Borstad et al. 1992). The CASI is a second generation imaging spectrometer whose predecessor was the Fluorescence Line Imager (Borstad et al. 1985). At the time of this study the CASI was operating in the range of 423 to 946 nm. A 512 pixel width spatial image is formed in "pushbroom" fashion by reading out the cross track information as the aircraft moves forward. The remaining elements are used to obtain dark and electronic offset reference values. Spectral data are collected across 288 elements in the along track dimension of the array. The spectral resolution of each element is 1.8 nm and the spatial resolution of each element is 1.2 rad. Integration times are typically 50 msec for spatial data and 100 msec for spectral data, the actual times are a function of ambient light levels, aircraft speed, and band selections.

In spatial or imaging mode the CASI operates like other pushbroom imagers except that band widths, positions and number are programmable during the flight. High spatial resolution imagery is collected in several spectral bands which can be programmed as narrow as 1.8 nm or wider. For aerial surveys the number of bands are limited to 15, laboratory situations may have up 288 bands. In this experiment, eight spectral bands in image mode were used:

Band Width(nm)

1	2	3	4	5	6	7	8
490-501	515-522	540-551	589-598	662-674	678-688	708-716	780-789

The band width selections were based on prior work with the Fluorescence Line Imager (Borstad et al. 1985) and preliminary analysis of CASI data collected from Pacific herring schools near Vancouver Island, British Columbia (Borstad et al. 1992). Band 8 was chosen to differentiate land and water interface, bands 5, 6, and 7 were selected to map phytoplankton, band 4 was the region where herring schools were first detected, and bands 1, 2, and 3 cover the range of wavelengths where capelin schools were easily recognized from background features.

In spectral or multispectrometer mode the CASI operates a group of line spectrometers, each with a resolution of 1.8 nm. The CASI also collects a coregistered monochromatic high spatial resolution image termed the "track recovery image" which is used to accurately locate each spectrometer in relation to known targets. Complete spectra (423-946 nm range) can be obtained for every pixel in a scanline for up to 39 spectrometer lines. in this experiment, both spectral and image data were collected over capelin schools, along with coincident colour aerial photographs. CASI image data were then transferred to a PC-based image processor for classification and analysis using PCI Limited's CASI/PACE software. Spectral data were analyzed using Borstad Associates Ltd.'s SPECPLOT(tm) software.

Results

Capelin schools on aerial photographs were easily identified as greyish patches with fluid edges. Other targets such as kelp beds and rocks are generally darker than schools and their margins tend to be more irregular. In cases where schools were difficult to detect imagery from the same location, taken on different days, was examined to see which features had changed either in shape or location, these being capelin schools.

The CASI has spectral and radiometric sensitivity to record small changes to the upwelling spectrum produced by the capelin as shown in the digital colour composite of coincident CASI image data (Fig. 3). A 'track recovery image' collected during a repeat flight over the same site (Fig. 4) shows the location of calibrated upwelling radiance spectra which can be used to determine spectral signatures from targets in the 'track recovery image'. Spectral signatures of a capelin school, nearby shallow water, and the difference between the two are displayed in Figure 5. Of the eight bands initially chosen, capelin schools were clearly observed in bands 1, 2 and 3 but not by the other five bands (Fig. 5).

The imagery was classified and enhanced to better differentiate schools from the background. An algorithm was developed to estimate the area of each school by filling in the school area and calculating an area (Fig. 3). School areas estimated from aerial photographs and from CASI digital imagery collected concurrently were significantly correlated ($n = 20$, $df = 18$, $r^2 = .98$) (Fig. 6). The number of comparisons was small, however in some instances where the digital imagery produced higher estimates it was later observed that the schools in the enhanced imagery were easier to interpret than on the photographs.

Discussion

Examination of the imagery collected during the 1989 comparative survey demonstrated that we can use the CASI sensor to collect and record data to identify capelin schools. Not only can the imagery be viewed as it is being recorded but the tapes can be examined immediately following each flight to quickly assess the data quality. Such is not the case with aerial photographs. Because schools can be differentiated from background features on the basis of characteristic upwelling radiance spectra, we now have an objective and rapid way to filter the data to select only records associated with capelin schools. This allows us to select wider band widths when the survey is run in spatial mode to collect school distribution data. Knowing which part of the visible spectrum can be used to differentiate schools from the background has aided in the development of algorithms to enumerate and calculate schools area digitally. In recent assessments this method has now replaced the subjective and laborious task of interpreting aerial photographs (Nakashima 1992).

Having characteristic upwelling radiance spectra for capelin schools will facilitate a reduction in spatial bands which in turn will reduce the amount of collected data and processing time. Instead of the eight spatial bands flown in 1989 we now use four bands. This reduction in the number of spatial bands has allowed us to increase the spectral range which in turn has permitted an increase in data quality. Consequently monitoring capelin schools has become easier and the time required for data processing shortened considerably.

In 1989 we were able to assign a spectral band specific to capelin schools which was very similar, but spectrally wider, than the one estimated for herring schools in March 1989 (Borstad et al. 1992). Having similar spectral signatures for two schooling pelagic species suggest that the CASI can be used to survey most pelagic species with minor changes in algorithms. At this stage of the development of the instrument we were unable to construct an unique spectral signature specific to capelin schools. However recent advances in instrumentation quality and more research into the relationship between what the spectrometer measures and what radiance absorption levels for capelin and other fish schools are may provide an answer.

The potential applications for this instrument in supplementing or expanding management and research opportunities for pelagic fish species may be substantial. For capelin research in the Newfoundland Region, the use of the CASI has allowed monitoring of data acquisition in real time, permitted immediate post-flight analysis of data, provided an objective means to enumerate and calculate areas of fish schools, and helped to archive data in a form which will facilitate other uses of school distributional data as inputs into GIS (Geographic Information System) databases. For example, the distribution of spawning schools may be compared in time (eg. daily, annually), with respect to temperature isotherms, bottom topography, or the location of fishing gears such as capelin traps.

This project is the first field demonstration that airborne imaging spectrometers can be configured to detect schooling fish. Combined with the classification and enhancement capability of image analysis systems and rapid PC-based or workstation analytical processing this sensor technology has the potential to provide a cost-effective, relatively easy to use tool to detect and measure schooling fish distributions.

Acknowledgments

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References

BORSTAD, G. A., H. R. EDEL, J.F.R. GOWER, and A. B. HOLLINGER. 1985. Analysis of test and flight data from the Fluorescence Line Imager. Can. Spec. Publ. Fish. Aquat. Sci. 83. 38 p.

BORSTAD, G. A., D. A. HILL, R. C. KERR, AND B. S. NAKASHIMA. 1992. Direct digital remote sensing of herring schools. Int. J. Remote Sensing 13: 2191-2198.

CARSCADDEN, J., B. S. NAKASHIMA, AND D. S. MILLER. 1993. Trends in abundance of capelin (Mallotus villosus) from acoustics, aerial surveys, and catch rates in NAFO Div. 3L, 1982-89. J. Northwest. Atl. Fish. Sci. (in press).

NAKASHIMA, B. S. 1988. Capelin school surface area index for NAFO Div. 3L, 1982-87. NAFO SCR Doc. 88/11. 11 p.

NAKASHIMA, B. S. 1992. Results of aerial surveys of capelin (Mallotus villosus) schools using the Compact Airborne Spectrographic Imager (CASI). NAFO SCR Doc. 92/5. 12 p.

NAKASHIMA, B. S., G. A. BORSTAD, D. A. HILL, and R. C. KERR. 1989. Remote sensing of fish schools: early results from a digital imaging spectrometer, p. 2044-2047. In Proceedings of IGARRS'89, 12th. Canadian Symposium on Remote Sensing, Vancouver, B.C., July 10-14, 1989.

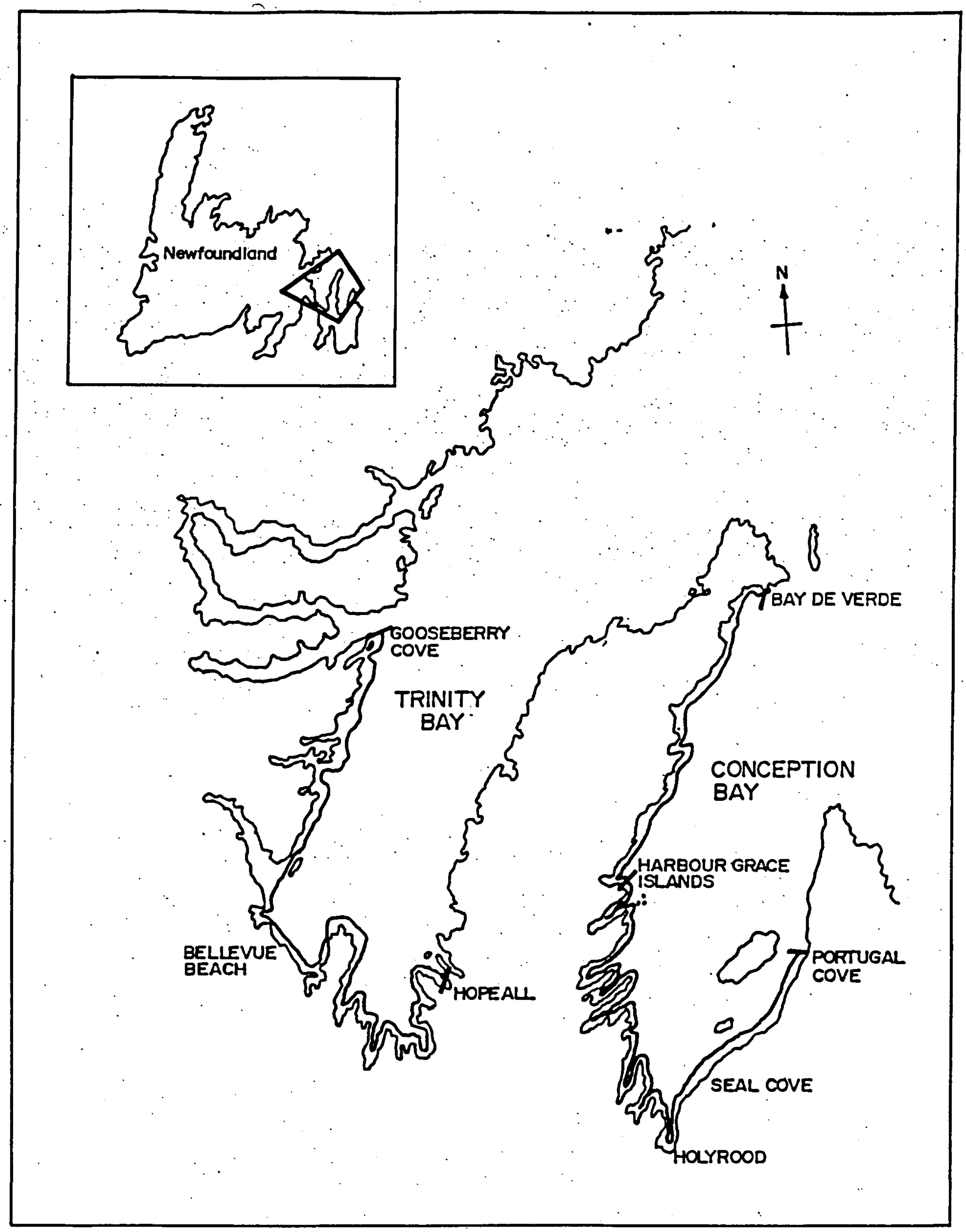

Figure 1. Aerial survey transects along the coastline of Trinity Bay and Conception Bay, Newfoundland.

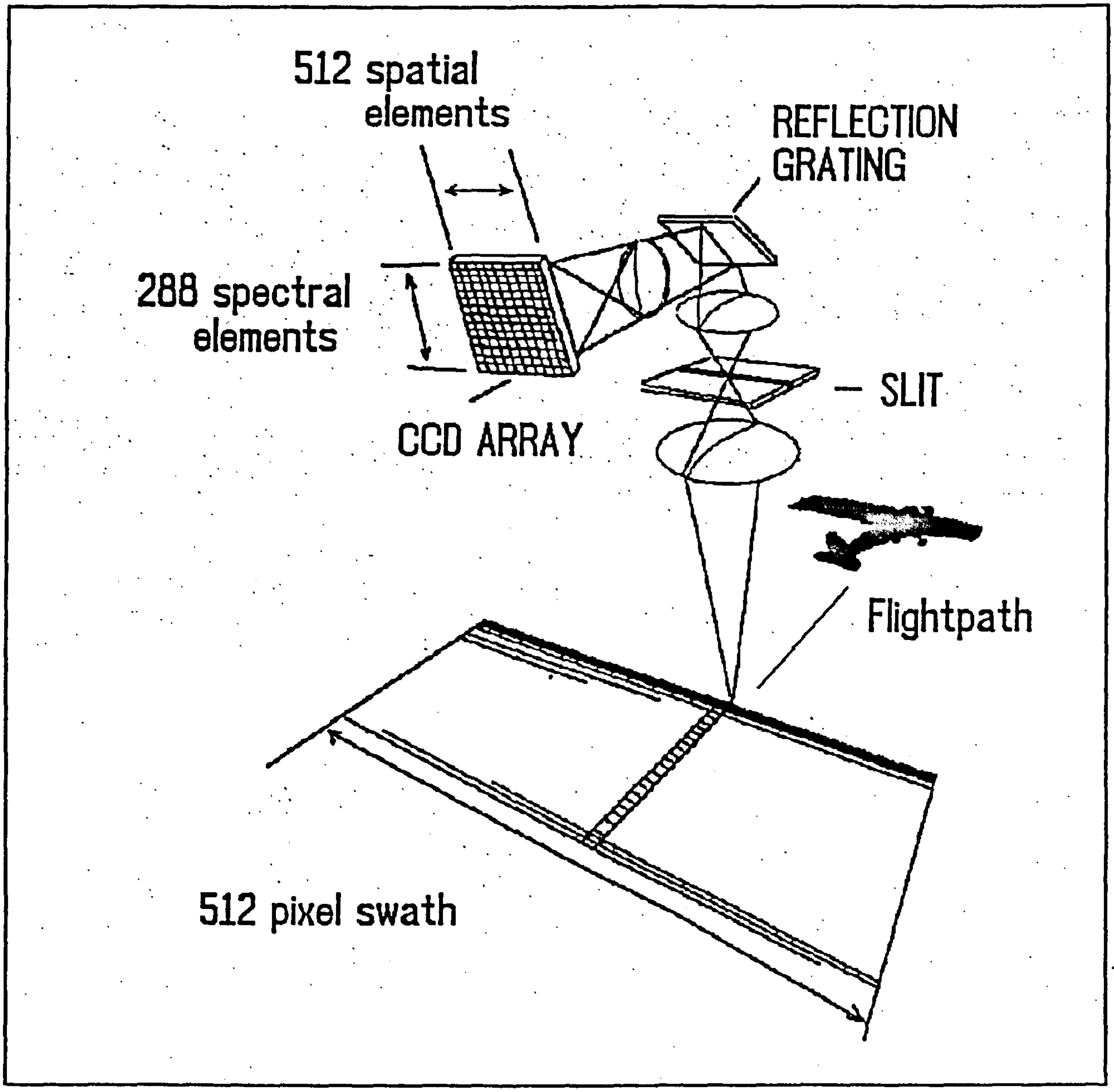

Figure 2. Schematic diagram of Compact Airborne Spectrographic Imager CASI.

Due to processing costs, only a limited number of colour prints are available. If you wish a colour print please contact the author at this meeting or at the address on the title page.

Figure 3. False colour digital CASI image of capelin schools (left panel). Capelin schools masked in red on right hand image used to estimate surface areas (right panel).

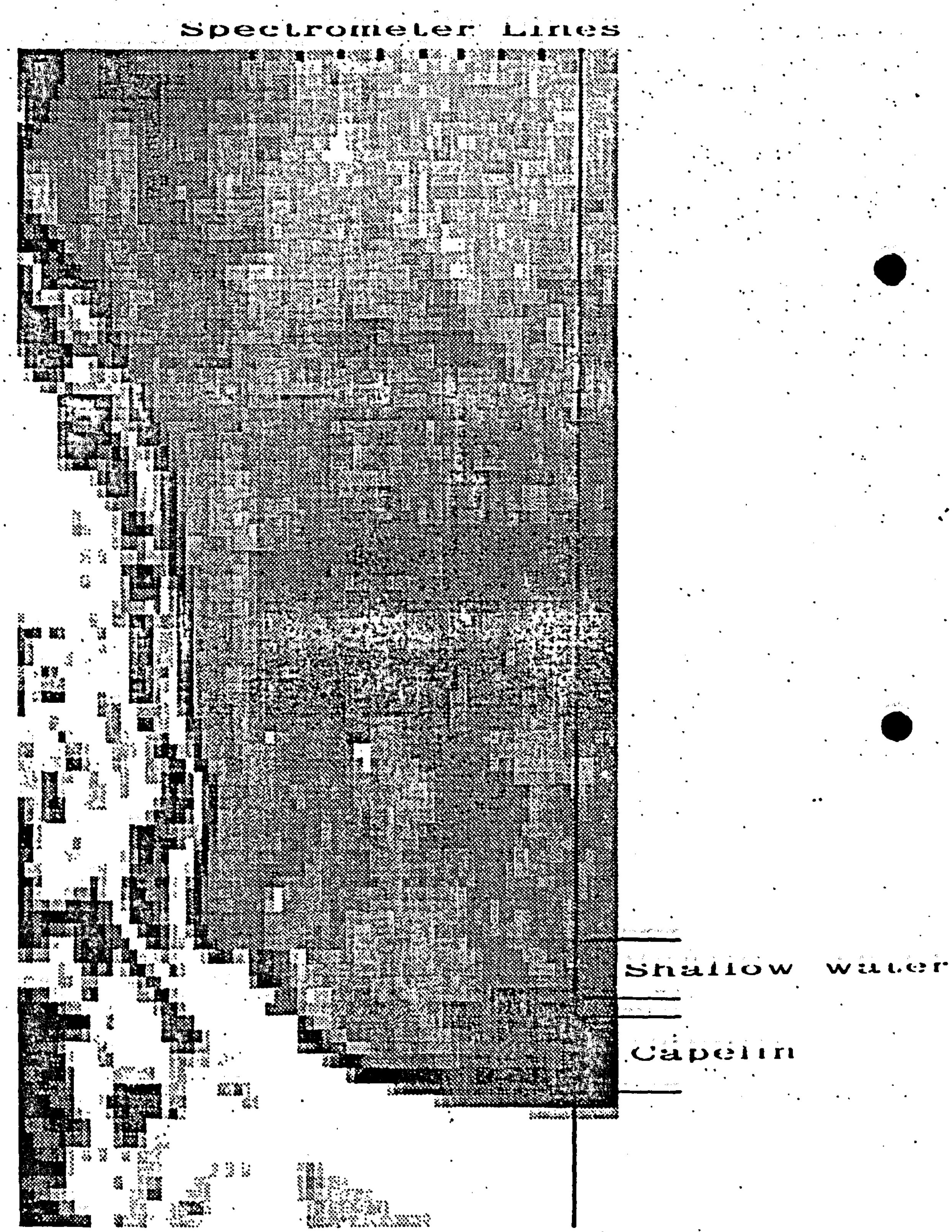

Figure 4. Track Recovery Image showing the column for which spectra in Figure 5 was selected for capelin schools and shallow water.

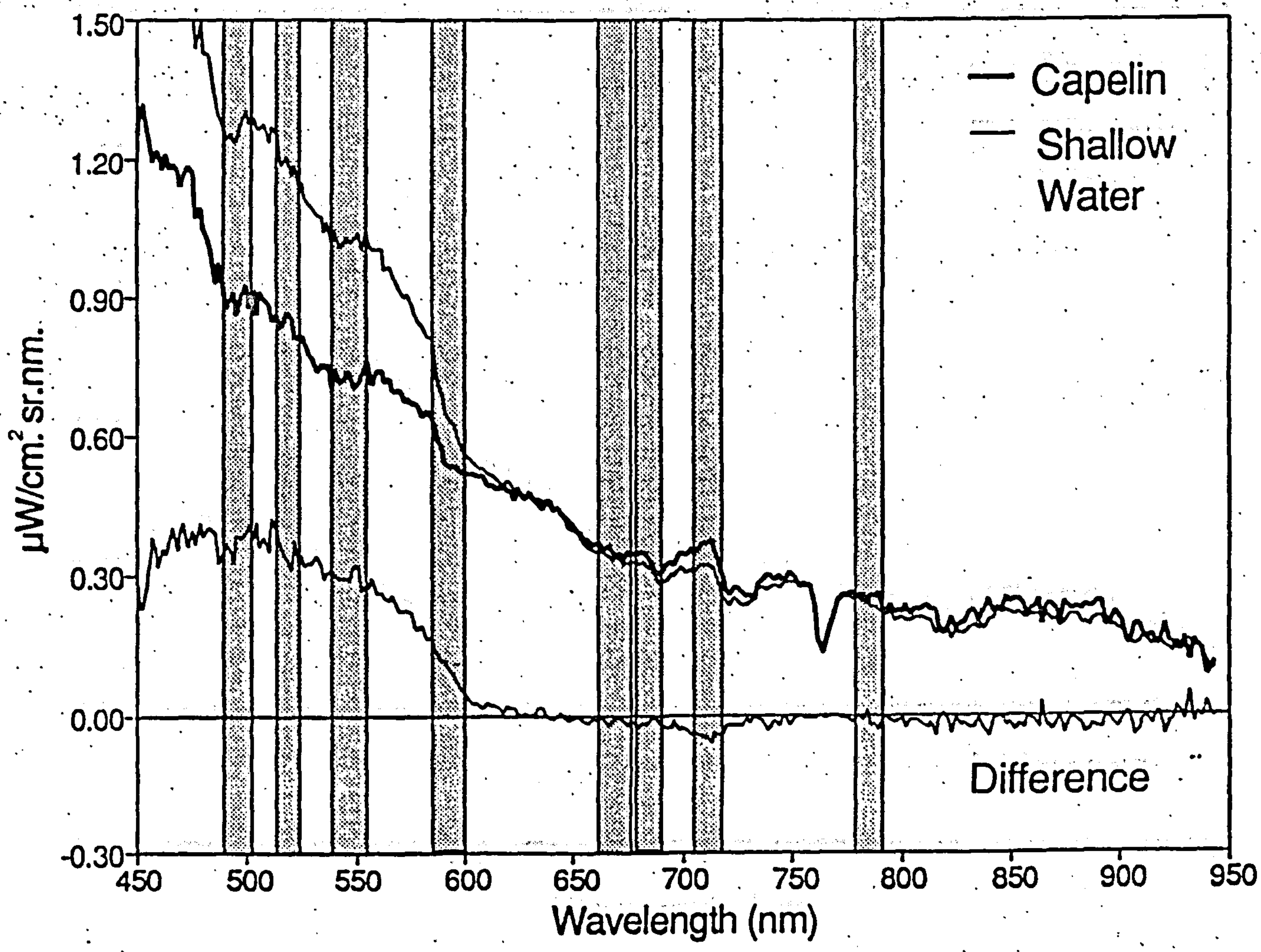

Figure 5. Upwelling radiance spectra of capelin and shallow water with the difference values. The eight band positions are indicated.

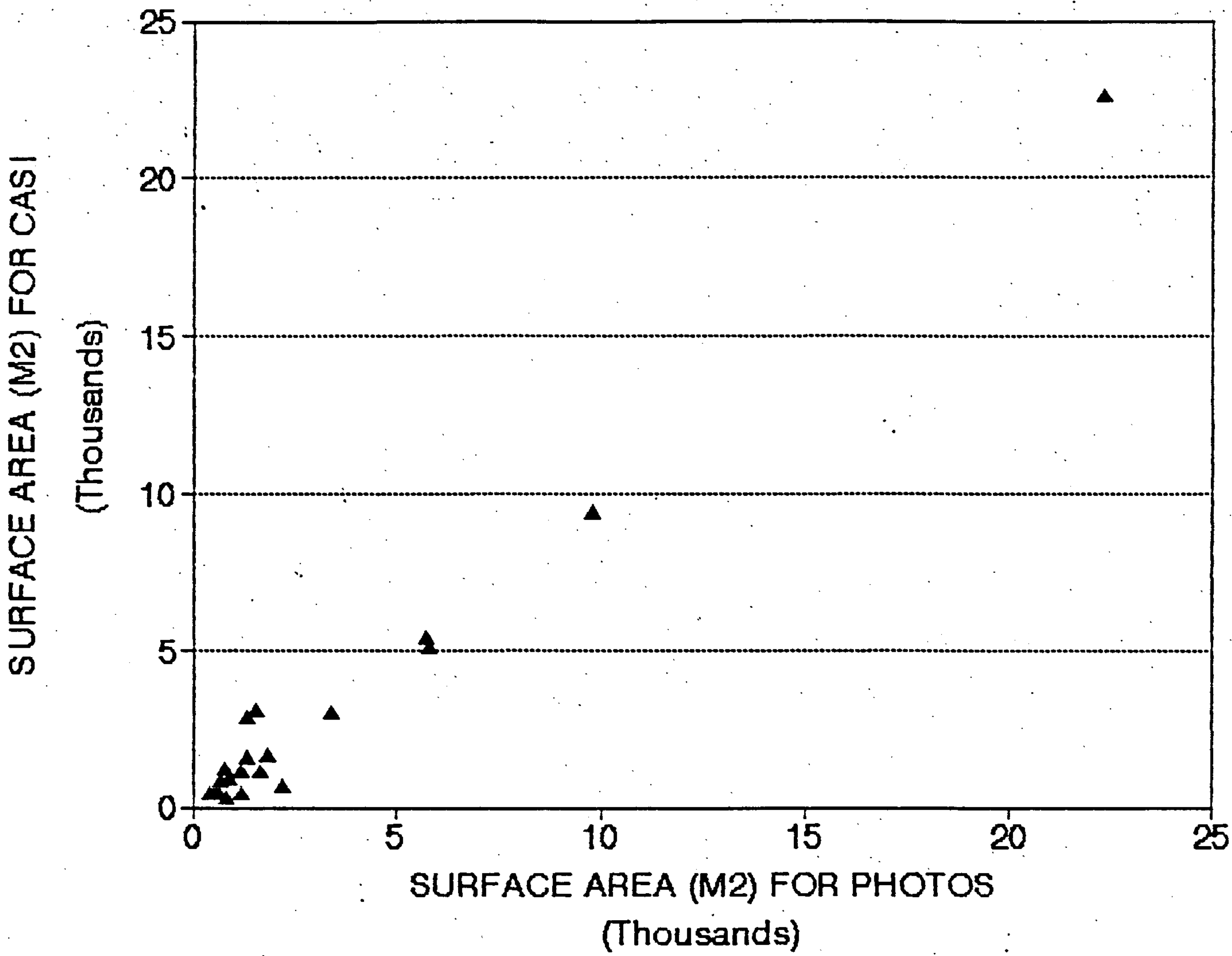

Figure 6. Comparison of capelin school surface areas measured from CASI digital imagery and from aerial colour photographs.